General Physics Lab 3

Motion with Constant Acceleration

Objectives:

- Explore accelerated motion for a car on an incline
- Collect force/acceleration data for analysis in Lab 4 (F = ma)

Equipment:

- Hot Wheels Car
- Hot Wheels Track (2 – 20” track segments)
- 40 Pennies
- Paper Clip (bent from Lab 2)
- Smartphone with
  - Phyphox App (acoustic stopwatch) or Normal Stopwatch
  - Level App
- Scotch Tape with Dispenser
- Duct Tape
- Stack of Books
- Triangular Wood Block
- Spring Balance
- Pillow
- Metric Measuring Tape

Physical Principles:

When an object undergoes constant acceleration, the change in displacement is related to the elapsed time in a quadratic form:

$$\Delta x = \frac{1}{2} a t^2 + v_0 t \qquad (1)$$

If the object begins at rest ($v_0 = 0$), this simplifies to:

$$\Delta x = \frac{1}{2} a t^2 \qquad (2)$$

A measurement of displacement and time can thus yield the constant acceleration.

$$a = \frac{2\Delta x}{t^2} \tag{3}$$

Galileo determined that objects in freefall all accelerate at the same rate of magnitude g = 9.80 m/s^2. Furthermore, he found that an object moving down a frictionless incline tilted at an angle θ relative to the horizontal accelerates down the incline with magnitude of,

$$|\vec{a}| = g\sin(\theta) \tag{4}$$

i.e., the steeper the incline angle, θ, the greater the acceleration.

Procedure:

In this lab, you will be rolling a penny-laden Hot Wheels car down an inclined track, measuring the distance it travels, Δx, and the time to cover that distance, t. At the same time, you will be measuring the force, F, down the incline for use in Lab 4.

Setup and procedures continue on the next page.

Please Note: If you are working with a lab partner, only one person can collect the data. Technically for this experiment, it wouldn't matter if you used different cars for different runs but in order to use this data for the next experiment, it must be done with a single car (constant mass).

Setup

The first thing you will need to do is load up a Hot Wheels car with pennies. The following instructions will explain the steps.

1. Break one of the 50 penny weights from Lab 2 into 5 stacks of 10 pennies each. You will use 4 stacks for this lab. Keep the bent paper clip nearby as you will use this too.
2. Use a long strip of Scotch tape to attach one penny stack to the top of your Hot Wheels car (see Fig. 1b). Wrap the tape around the middle of the car to avoid the wheels. If the tape is in contact with the wheels, it will cause friction and slow the car.
3. Use another strip of tape to attach two more penny stacks in front of and behind the first stack (see Fig. 1c). The tape should only go around the first stack, not under the car.
4. Tape the fourth stack on top of the first as shown in Fig. 1d.
5. Tape the bent paper clip to the stack of pennies at the back of the car (see Fig. 1e). Double check that no tape is touching the wheels. If it is, adjust the tape or trim that part off.
6. The last thing to do with the car is weigh it on the spring balance. Without the car, hang the balance from the top hook and zero it if necessary. Then hang the car with the pennies on the hook and record its mass in kg (convert from g to kg if necessary).

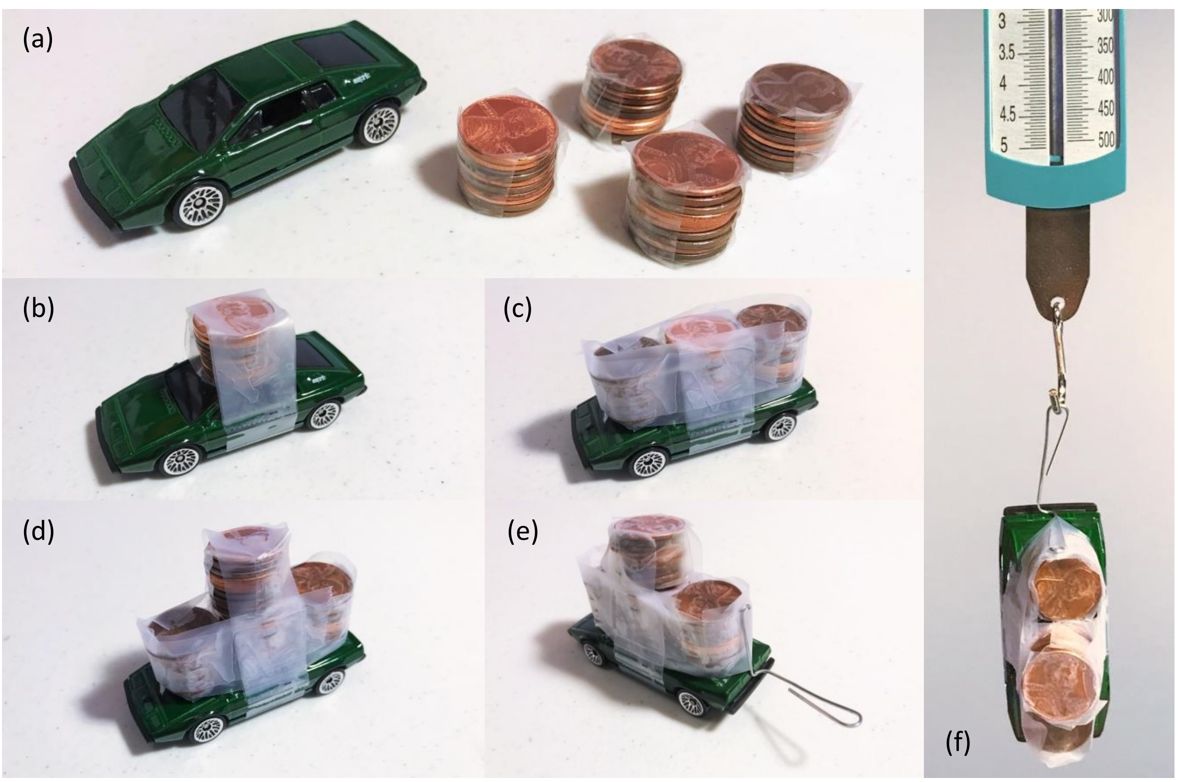

Fig. 1: Load 40 pennies onto the Hot Wheels car. When you finish, zero the spring balance and weigh the car.

The second thing to set up is the track for the car. This will need to be angled and supported so that it won't sag in the middle.

1. Connect 2 Hot Wheels track sections together to make one long track 40 inches in length.
2. Use 2 strips of Scotch tape to tape the sides of each track together (see Fig. 2). Fold each piece of tape over the edge of the track so it holds it together on the inside and outside edges. Smooth it down so no tape sticks out into the path of the car. The reason for the tape is to keep the edges together so the car can roll past without bumping into them.
3. Wrap a strip of duct tape around the end of the track that has a connector (see Fig. 3a). This piece of tape will mark the starting point for the Hot Wheels Car.
4. Use duct tape to attach the triangular wood block under the taped end of the track. Orient the block as shown in Fig. 3b.

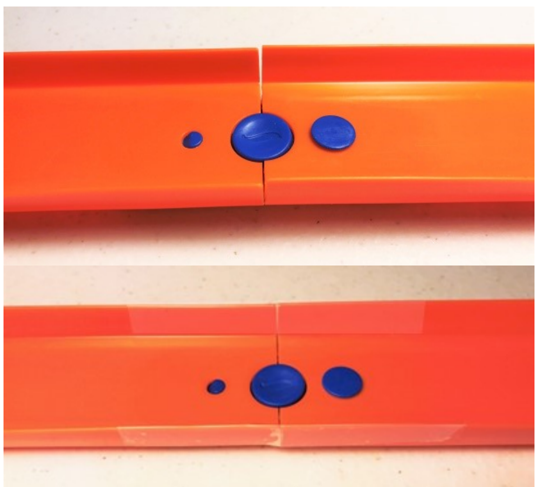

Fig. 2: Connect the two Hot Wheels track sections. Then tape the two edges on each side of the track.

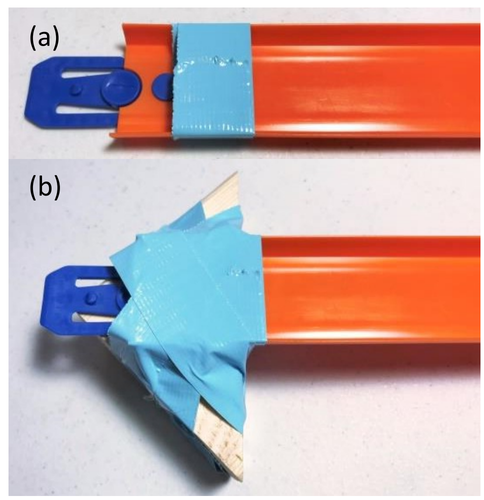

Fig. 3: (a) Tape marks the starting point. (b) Wood block taped to the end of the track.

5. Next, measure the length of the track. The length we need is the distance, Δx, the car will travel along the track. To do this, lay the track on a flat surface with the back of the car against the tape you added in Fig. 3a. Then measure from the front of the car (starting point) to the end of the track (see Fig. 4). Record Δx in meters.

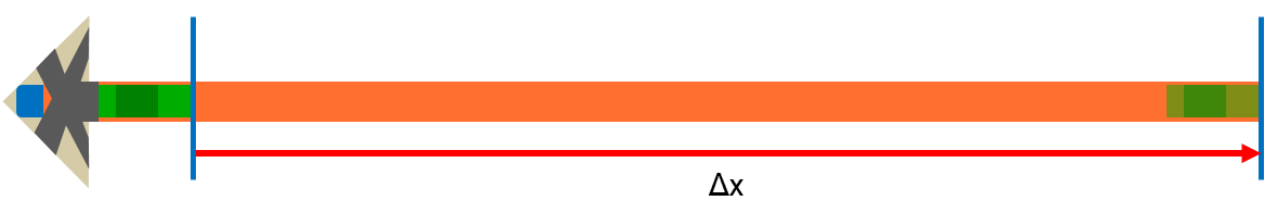

Fig. 4: Length Measurement from the front of the car to the end of the track. This is the distance (Δx) the car will travel along the track.

6. Make a stack of books about 30 cm high and prop up the wood block end of the track on the books. The track/wood block combo should touch the books at two points (see Fig. 5a). The wood block will touch at the back and the track will touch in the front, forming a triangle as shown. This will help stabilize the angle of the track. The angle will be adjusted later for separate runs by removing books from the stack.

   Note: If you do not have books to use for this purpose, get creative and find other objects to prop up and support the track. Whatever objects you use, the track height needs to be adjustable in the range of about 10 – 40 cm. If you go any higher or lower, the incline angles will be outside the recommended range (5° – 25°) and the experiment may not work.

7. Lightly tape the block to the stack of books to keep it from sliding and changing the angle. Make sure the tape won't damage the book first. Slick hardcover books like textbooks usually do fine with duct tape, especially if you remove the tape when finished.
8. Make a second stack of books about half as high as the first and place this under the middle of the track to keep it from sagging.
9. Place the Scotch tape dispenser at the bottom end of the track so that the car will hit it and make a sharp noise when it reaches the bottom.
10. Place a pillow, jacket, or something padded to stop the car from rolling off the table.

Fig. 5: Hot Wheels Track propped up with books. The tape dispenser and a pillow are at the end.

Data Collection

Complete the following steps for 5 different track incline angles in the range of 5° – 25°.

1. Open an angle measurement app on your smartphone and place the phone on the track over the triangle area where the track is most supported and won't sag (see Fig. 6). Record the angle (θ) in degrees.
2. Place the spring balance on the track with the hook end pointed downhill. Hold it in place by the top ring, pull the hook to make sure it is fully extended, and then zero the spring balance at that track angle.
3. Attach the Hot Wheels car to the hook on the spring balance, hold the balance by the top ring, and let the weight of the car exert a force along the track. Record the force in Newtons displayed on the spring balance. This force is the downhill component of the car's weight, which acts to accelerate it down the track.
4. Open the Phyphox app on your smartphone and open the "Acoustic Stopwatch" tool. Place your phone at the bottom end of the track with the microphone (probably at the bottom end of your phone) closest to the tape dispenser. Tap the play button to start the stopwatch. If necessary, adjust the threshold (as described in Lab 0).
5. Place the Hot Wheels car at the top of the track with the back of the car up against the tape. Hold onto the car by the paper clip loop at the back as this will provide an easy way to release the car quickly. Alternatively, you could place a finger on top of the car and lift up to release the car down the ramp.
6. Use a pen, your hand, or something that won't break and smack it on the table right as you release the car. This sharp sound will start the acoustic stopwatch, and the sound of the car crashing into the tape dispenser will stop it. Mark down the time in seconds.

   If the acoustic stopwatch does not work with your phone, use a regular stopwatch/app

Fig. 6: Using a smartphone to measure the angle of inclination.

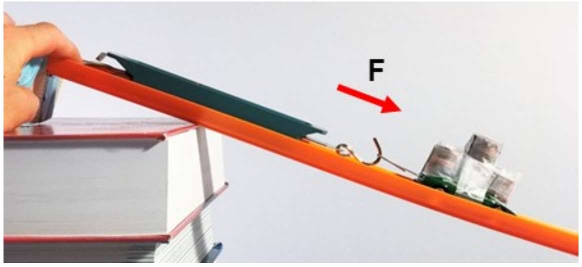

Fig. 7: Measuring the downhill component of the loaded Hot Wheels' weight.

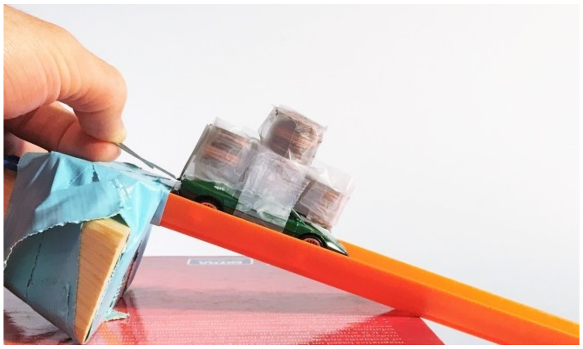
Fig. 8: Hot Wheels car at the top of the track ready to be released.

to time the runs. Make sure you start it precisely when you release the car and stop it when the car hits the tape dispenser.

When doing this step (with either type of stopwatch), be careful to smack the table (start the stopwatch) precisely when you release the car. If you release it too soon/too late, the time will be too long/too short and it will skew the resulting acceleration.

7. Time at least 2 more runs for this angle (at least 3 total runs per angle) and mark down the time from each run. Calculate the average (Eq. 5) of these three times and record this as the average time in seconds. If one of the times is much shorter or longer than the others, throw out this value and try it again. If you have time to do more runs at each angle, the resulting acceleration will be more accurate.

$$Average_N = \frac{t_1+t_2+\ldots+t_N}{N}, \quad Average_3 = \frac{t_1+t_2+t_3}{3} \qquad (5)$$

Remove some books from the stack(s) to decrease the angle of the track. Try to decrease the angle by about 3-5 degrees. Make sure everything is set back up for the new angle and repeat these data collection steps. Do all of this for 5 angles within the range of 5° – 25°.

Analysis:

Use the average times, t, and distance, Δx, to determine the acceleration of the Hot Wheels car for each angle, θ, using Eq. (3). A comparison of Eq. (4) with the equation of a straight line,

a = g sinθ + 0
y = mx + b (6)

suggests that a plot of acceleration, a (y-axis) vs. sinθ (x-axis) should yield a slope equal to g, the acceleration due to gravity.

Calculate sinθ by hand or in a spreadsheet (Google Sheets or Excel). Note that if you use a spreadsheet to calculate sine, you will have to convert the angles to radians. This can be accomplished inside the sine function like this.

=SIN(RADIANS(cell))

Also, note that we can include the point (sinθ, a) = (0,0) because if the slope was completely flat (θ = 0), the car would not have accelerated down the track (a = 0).

Use Google Sheets, Excel, or Graphical Analysis to generate a scatter plot of a vs. sinθ and perform a linear trendline fit. Compare the slope to g using a percent error.

$$\%Error = \frac{|9.8 - slope|}{9.8} \times 100\% \qquad (7)$$

Note: The force measurements you took from the spring balance will be used as data for Lab 4 (F = ma).